[Name of the Document] SPECIFICATION

[Title of the Invention] PROJECTION EXPOSURE APPARATUS AND EXPOSURE METHOD

[ABSTRACT]

[Summary]

[Object] It is an object of the present invention to provide a projection exposure apparatus and an exposure method, each of which is low in fluctuation of an imaging position and of imaging performance near an optical axis of the projection optical system in comparison with those in normal use even if the projection optical system is used under liquid immersion condition.

[Constitution] A projection exposure apparatus having a projection optical system (2) for transferring a pattern (1a) drawn on an original plate (1) to a photosensitive surface (5a) of a substrate (5), wherein an attachment lens (4) is disposed insertably/extractably with respect to a space between the lens surface of the projection optical system (2) closest to the substrate (5) and the photosensitive surface (5a), wherein the space between the under surface of the attachment lens (4) and the photosensitive surface (5a) is configured to be immersed in liquid, and wherein the radius of curvature (R_1) of the lens surface on the original plate (1) side of the attachment lens (4) is substantially equal to a distance (d_1) on an optical axis (Z) from the lens surface on the original plate (1) side

to the photosensitive surface (5a).

[Scope of Claims for Patent]

[Claim 1] A projection exposure apparatus having a projection optical system for transferring a pattern drawn on an original plate to a photosensitive surface of a substrate, wherein:

an attachment lens is disposed insertably/extractably with respect to a space between the lens surface of the projection optical system closest to the substrate and the photosensitive surface;

a space between the under surface of the attachment lens and the photosensitive surface is configured to be immersed in liquid; and

a radius of curvature of the lens surface on the original plate side of the attachment lens is substantially equal to a distance on an optical axis from the lens surface on the original plate side to the photosensitive surface.

[Claim 2] The projection exposure apparatus according to claim 1, wherein the radius of curvature of the lens surface on the substrate side of the attachment lens is substantially equal to a distance on the optical axis from the lens surface on the substrate (5) side to the photosensitive surface.

[Claim 3] A projection exposure apparatus having a projection optical system for transferring a pattern drawn on an original plate to a photosensitive surface of a substrate, wherein a radius of curvature of the lens surface on the substrate side of the projection optical system is

substantially equal to a distance on an optical axis from the lens surface on the substrate side to the photosensitive surface.

[Claim 4] A method of performing exposure using the projection exposure apparatus according to one of claim 1 to claim 3, the method comprising:

an illumination step of illuminating the original plate with a predetermined exposing light; and

an exposure step of exposing the pattern image on the original plate to the photosensitive surface of the substrate through the projection optical system.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to a projection exposure apparatus having a projection optical system for exposing and transferring a pattern drawn on an original plate onto a substrate, and exposure method.

[0002]

[Background Related Art]

In recent years, there is a demand for miniaturization of patterns transferred to a wafer as a photosensitive substrate. In order to achieve this, the following two methods are conceivable: decreasing an exposure wavelength; and increasing the numerical aperture of a projection optical system. Among them, an immersion type projection exposure apparatus has conventionally been suggested as a method of

increasing the numerical aperture of the projection optical system. In the immersion type projection exposure apparatus, all or a wafer-side part of the space between a lens surface of the projection optical system closest to the wafer and the wafer, in other words, a space of the working distance (hereinafter, referred to as a working space) is filled with oil or some other liquid. While the refractive index of air occupying the working space in normal use is 1.0, the reactive index of oil is about 1.6, for example. Therefore, it is possible to increase the numerical aperture on the wafer side of the projection optical system to achieve the miniaturization of an exposed pattern by replacing all or the wafer-side part of the working space with a liquid having a high refractive index as described above.

[0003]

[Problems to be Solved by the Invention]

The above conventional immersion type projection exposure apparatus has been incapable of securing an equal imaging performance between normal use in which the working space is filled with air or some other gas and liquid immersion use in which the liquid occupies all or the wafer-side part of the working space in order to achieve pattern miniaturization. For example, a method of using the projection exposure apparatus under liquid immersion condition will be discussed in a situation where a parallel plate glass is placed on the boundary between the gas and the liquid. In this instance, the following three problems occur.

[0004]

The first problem is that a displacement of imaging position of the projection optical system due to refraction of light on the incidence plane of the parallel plate glass in liquid immersion use. Therefore, it is necessary to move the projection optical system or the wafer so as to secure the focal length. Moreover, the imaging position may be incapable of being adjusted onto the wafer depending on the conditions in liquid immersion use. The second problem is that a spherical aberration occurs due to the parallel plate glass placed on the boundary between the gas and the liquid in liquid immersion use. This deteriorates the imaging performance in liquid immersion use. The third problem is that the environmental variation significantly changes the imaging performance or the imaging position in liquid immersion use. More specifically, the refractive index of the liquid remarkably changes according to the environmental variation such as a temperature change in comparison with the refractive index of the gas, which leads to unstable imaging performance or imaging position. Therefore, an object of the present invention is to provide a projection exposure apparatus and an exposure method, each of which is low in fluctuation of an imaging position and of imaging performance near an optical axis of the projection optical system in comparison with those in normal use even if the projection optical system is used under liquid immersion condition.

[0005]

[Means to Solve the Problem]

The present invention has been suggested to overcome the foregoing various problems. More specifically, with the reference numerals in FIG. 1 and FIG. 2 of the attached drawings added in parentheses, according to one aspect of the present invention, there is provided a projection exposure apparatus having a projection optical system (2) for transferring a pattern (1a) drawn on an original plate (1) to a photosensitive surface (5a) of a substrate (5), wherein an attachment lens (4) is disposed insertably/extractably with respect to a space between the lens surface of the projection optical system (2) closest to the substrate (5) and the photosensitive surface (5a), wherein a space between the under surface of the attachment lens (4) and the photosensitive surface (5a) is configured to be immersed in liquid, and wherein a radius of curvature (R_1) of the lens surface on the original plate (1) side of the attachment lens (4) is substantially equal to a distance (d_1) on an optical axis (Z) from the lens surface on the original plate (1) side to the photosensitive surface (5a). In this regard, with the reference numerals in FIG. 3 of the attached drawings added in parentheses, preferably a radius of curvature (R_2) of the lens surface on the substrate (5) side of the attachment lens (4) is substantially equal to a distance (d_2) on the optical axis (Z) from the lens surface on the substrate (5) side to the photosensitive surface (5a).

[0006]

Moreover, with the reference numerals in FIG. 1 and FIG. 4 of the attached drawings added in parentheses, according to another aspect of the present invention, there is provided a projection exposure apparatus having a projection optical system (2) for transferring a pattern (1a) drawn on an original plate (1) to a photosensitive surface (5a) of a substrate (5), wherein a radius of curvature (R_2) of the lens surface on the substrate (5) side of the projection optical system (2) is substantially equal to a distance (d_2) on an optical axis (Z) from the lens surface on the substrate (5) side to the photosensitive surface (5a). Moreover, with the reference numerals in FIG. 1 of the attached drawings added in parentheses, according to still another aspect of the present invention, there is provided a method of performing exposure using the projection exposure apparatus having the above configuration, the method comprising: an illumination step of illuminating the original plate (1) with a predetermined exposing light; and an exposure step of exposing the pattern image (1a) on the original plate (1) to the photosensitive surface (5a) of the substrate (5) through the projection optical system (2).

[0007]

[Embodiments]

The preferred embodiments of the present invention will be described below with reference to drawings. Referring to FIG. 1 and FIG. 2, there is shown a first embodiment of a projection exposure apparatus according to the present

invention. FIG. 1 shows the projection exposure apparatus in normal use according to the first embodiment of the present invention. In the first embodiment, an image on a pattern surface 1a of a reticle 1 is formed onto an image surface 5a (photosensitive surface) of a wafer 5 in an exposure method including an illumination step and an exposure step. More specifically, a luminous flux emitted from a light source 10 such as a KrF excimer laser light source passes through an illumination optical system 11 and uniformly illuminates the pattern surface 1a of the reticle 1 as an original plate mounted on a reticle stage 12. The exposing light emitted from the pattern surface 1a of the reticle 1 forms the image of the pattern surface 1a to the image surface 5a of the wafer 5 mounted on an XY stage 8 through the projection optical system 2. Note that the term "normal use" means a state in which a working space is filled only with air.

[0008]

On an XY stage 8, an attachment lens 4 held by a lens holder 3 is mounted with a rotary shaft 7 put between the XY stage 8 and the attachment lens 4. The attachment lens 4 is rotatable around the rotary shaft 7. When being rotated 180° from the position shown in FIG. 1, the attachment lens 4 is disposed just under the projection optical system 2. In this condition, the optical axis of the attachment lens 4 is coincident with the optical axis of the projection optical system 2. Furthermore, a liquid shield 6 in the form of box is placed on the XY stage 8. In FIG. 1, only the cross

section of the liquid shield 6 is shown for simplification. A partial space on the wafer 5 side of the working space can be filled with liquid by supplying oil or some other liquid into the space enclosed by the liquid shield 6. When the projection exposure apparatus according to the first embodiment is used in a state of being immersed, the attachment lens 4 is disposed just under the projection optical system 2 and then the liquid is supplied inside the liquid shield 6. In this condition, air exists between the top surface of the attachment lens 4 (the surface on the reticle 1 side) and the under surface of the projection optical system 2 (the closest surface to the wafer 5). On the other hand, the liquid exists between the under surface of the attachment lens 4 (the surface on the wafer 5 side) and the wafer 5. A dashed line M in FIG. 1 indicates a border line between the air and the liquid.

[0009]

Referring to FIG. 2, there is shown a diagram illustrating an enlarged part in the vicinity of the attachment lens 4 in the projection exposure apparatus in liquid immersion use according to the first embodiment of the present invention. As described above, air A exists in the space on the top surface side of the attachment lens 4 and liquid L exists in the space on the under surface side of the attachment lens 4 in liquid immersion use. In addition, the refractive index of the attachment lens 4 in the first embodiment is substantially equal to the refractive index of

the liquid L. The shape of the top surface of the attachment lens 4 is formed in such a way that all beams of light K that form an image at the center of the image surface 5a on the wafer 5 are incident perpendicularly. In other words, the center of curvature on the top surface of the attachment lens 4 is coincident with the center of the image surface 5a in normal use in which the attachment lens 4 and the liquid L do not intervene. Moreover, the radius of curvature R_1 on the top surface of the attachment lens 4 satisfied the following expression:

$R_1=d_1$ (1)

d_1: Distance on the optical axis Z from the top surface of the attachment lens 4 to the image surface 5a of the wafer

[0010]

On the other hand, the shape of the under surface of the attachment lens 4 is formed in plane. As described above, the refractive index of the attachment lens 4 is equal to that of the liquid L, and therefore all the beams of light K that form an image near the center of the image surface 5a are not refracted almost at all also in the under surface of the attachment lens 4, similarly to the top surface. Accordingly, the convergence half-angle in liquid immersion use is equal to the convergence half-angle in normal use. In this condition, the numerical aperture NA on the wafer 5 side of the projection optical system 2 is obtained by:

$NA=n\sin\theta$

n: Refractive index of liquid relative to air

θ: Convergence half-angle

In addition, resolution Δr is obtained by:

$\Delta r = k\lambda_0/NA$

λ_0: Refractive index of exposing light in air

k: Constant

[0011]

Therefore, it is possible to improve the numerical aperture to n times and the resolution near the center of the image surface 5a to 1/n in liquid immersion use in comparison with those in normal use. Furthermore, all the beams of light K that form an image at the center of the image surface 5a are not refracted by the attachment lens 4 in the first embodiment, and therefore no spherical aberration occurs. Furthermore, if the chromatic dispersion of the attachment lens 4 is equal to that of the liquid L, no axial chromatic aberration occurs. This substantially keeps the imaging performance that will be achieved in normal use, even in liquid immersion use, in the image surface 5a near the optical axis Z. Furthermore, there is no change in imaging position of the projection optical system 5 between immersion use and normal use.

[0012]

Subsequently, a second embodiment of the projection exposure apparatus according to the present invention will be described with reference to FIG. 3. The second embodiment differs from the first embodiment only in the shape of attachment lens 4. Referring to FIG. 3, there is shown a

diagram illustrating an enlarged part near the attachment lens 4 in the projection exposure apparatus in liquid immersion use according to the second embodiment of the present invention. The shape of the top surface of the attachment lens 4 of the second embodiment is the same as the top surface of the attachment lens 4 of the first embodiment. In other words, the relation of expression (1) is satisfied in the top surface.

[0013]

On the other hand, while the under surface of the attachment lens 4 in the first embodiment is plane, the under surface of the attachment lens 4 in the second embodiment has curved shape. Similarly to the top surface of the attachment lens 4, the under surface thereof in the second embodiment is formed in such a way that all the beams of light K, which form an image at the center of the image surface 5a of the wafer 5, are incident perpendicularly. In other words, the center of curvature of the under surface of the attachment lens 4 is coincident with the center of the image surface 5a in normal use. The radius of curvature R_2 of the under surface of the attachment lens 4 satisfies the following expression:

$$R_2=d_2 \qquad (2)$$

d_2: Distance on the optical axis Z from the under surface of the attachment lens 4 to the image surface 5a of the wafer

[0014]

According to the second embodiment, the aberration and

the imaging position stay relatively unchanged even if the refractive index differs between the attachment lens 4 and the liquid L or if the refractive index of the liquid L changes according to the environmental variation such as a temperature change. More specifically, the beams of light K of all wavelengths forming an image at the center of the image surface 5a are not refracted independently of the refractive index and the chromatic dispersion of the liquid L also on the under surface of the attachment lens 4. Therefore, high resolution can be achieved in liquid immersion use also in the second embodiment, similarly to the first embodiment. Moreover, the imaging position in the projection optical system 2 does not change and no change occurs in the axial chromatic aberration and the spherical aberration in the image surface 5a in comparison between normal use and immersion use. Therefore, the imaging performance is maintained on the image surface 5a near the optical axis Z. Moreover, no change occurs in the imaging position, the axial chromatic aberration, and the spherical aberration even if the refractive index of the liquid L changes due to a temperature change or the like.

[0015]

Subsequently, a third embodiment of the projection exposure apparatus according to present invention will be described with reference to FIG. 4. While a part of the space on the wafer 5 side of the working space has been immersed in the liquid in liquid immersion use in the first

and the second embodiments, all of the working space is immersed in the liquid in liquid immersion use in the third embodiment. More specifically, the surface of the projection optical system 2 closest to the wafer 5 is immersed in the liquid in liquid immersion use. Therefore, the projection exposure apparatus of the third embodiment is required to have the top surface of the liquid shield 6 in FIG. 1 higher than the under surface of the projection optical system 2. Furthermore, there is no need to use the lens holder 3, the attachment lens 4, and the rotary shaft 7 in FIG. 1 for use in liquid immersion use of the first and second embodiments.

[0016]

Referring to FIG. 4, there is shown an enlarged surface of the projection optical system 2 closest to the wafer 5 in the projection exposure apparatus in liquid immersion use. The shape of the surface of the projection optical system 2 closest to the wafer 5 is the same as the shape of the under surface of the attachment lens 4 in the second embodiment. In other words, the relation of the expression (2) is satisfied regarding the under surface. On the other hand, while the projection optical system 2 shown in FIG. 4 is used also in normal use, no refraction occurs in all beams of light K, which form an image near the center of the image surface 5a, in the same manner as in liquid immersion use. Also in the third embodiment, high resolution is achieved in liquid immersion use similarly to the second embodiment. Moreover, the imaging position in the projection optical

system 2 does not change and no change occurs in axial chromatic aberration and spherical aberration in the image surface 5a in comparison between normal use and immersion use. Therefore, the imaging performance is maintained on the image surface 5a near the optical axis Z. Moreover, no change occurs in the imaging position, the axial chromatic aberration, and the spherical aberration even if the refractive index of the liquid L changes due to a temperature change or the like.

[0017]

[Effect of the Invention]

As described hereinabove, according to the present invention, the projection exposure apparatus can be shared between normal use and immersion use. Moreover, it is possible to provide a projection exposure apparatus in which there is substantially no change in the imaging position and the imaging performance near the optical axis even in liquid immersion use. Furthermore, it is possible to provide a projection exposure apparatus and an exposure method, each of which is little affected by a change in the refractive index of the liquid.

[Brief Description of the Drawings]

[Fig. 1]

It is a diagram showing a projection exposure apparatus according to a first embodiment of the present invention.

[Fig. 2]

It is a diagram showing a state of the projection

exposure apparatus in liquid immersion use according to the first embodiment of the present invention.

[Fig. 3]

It is a diagram showing a state of the projection exposure apparatus in liquid immersion use according to a second embodiment of the present invention.

[Fig. 4]

It is a diagram showing a state of the projection exposure apparatus in liquid immersion use according to a third embodiment of the present invention.

[Explanation of the Reference Numerals]

1 Reticle

1a Pattern surface

2 Projection optical system

3 Lens holder

4 Attachment lens

5 Wafer

5a Image surface

6 Liquid shield

7 Rotary shaft

8 XY stage

10 Light source

11 Illumination optical system

12 Reticle stage

Z Optical axis

K Beam of light

A Gas

L Liquid